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Programming Assignment Report - #3

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Abstract

In this programming assignment, I developed a fluid simulation using Smoothed Particle Hydrodynamics (SPH) to test the effectiveness of a protective wall against a broken dam. The simulation focused on essential setups, the implementation of the SPH algorithm, and handling boundary conditions.

The simulation included 300 water particles representing the water block, along with defined boundaries such as the wall and the house. The SPH algorithm was implemented using the poly6 kernel and its gradient to compute density and pressure. Forces from pressure gradient and gravity were calculated, and particle acceleration was used to update positions and velocities.

Handling boundary conditions to prevent water particles from leaving the boundary or penetrating the wall and house was implemented. Also by considering the density of water, accurate mass values were assigned to the particles. The simulation aimed to determine if the protective wall would be successful in preventing damage to the house.[1]

After running the simulation, findings were reported regarding the potential damage to the house, the minimum height to protect it, and the minimum distance between the wall and the house needed for protection. Additionally, the simulation investigated the impact of increasing simulation accuracy by adjusting the number of particles or the time step size on the previous findings.

1 Simulation

1.1 Basic setups

My implementation is done Python. The visualization is accomplished through the Pygame library in 2D. There are 3 files in total, the fluidsimulator which has the fluid simulation class, the visualizer which has the visualization code, and the main for running the code. The output frames will be saved in the frames directory.

The initial world space has a height of 4m and a width of 6m. The water block consists of 300 particles and is initially positioned as a rectangular block on the very far left of the world space. It has a height of 3m and a width of 1m. The mass of each water particle can be calculated using the formula:

$$\text{Mass} = \text{Volume} \times \text{Density}$$

Given that the density of water is 997kg/m^3, and assuming a rectangular shape for the water block with a height of 3m, a width of 1m, and a depth of 1m, the volume of each water particle is:

$$\text{Volume} = \text{Height} \times \text{Width} \times \text{Depth} = 3m \times 1m \times 1m = 3m^3$$

Substituting the values into the mass formula:

$$\text{Mass} = 3m^3 \times 997kg/m^3 = 2991kg$$

Therefore, the mass of each water particle is 2991kg.

The wall is a rectangular rigid object located 2m from the far left of the world space. It has a height of 1m and a width of 0.5m. The house is a square rigid object situated on the far right side of the wall. It has a height and width of 0.5m.

1.2 Implementation of the SPH Algorithm

To implement the Smoothed Particle Hydrodynamics (SPH) algorithm, I followed the steps outlined below:

1. Use the poly6 kernel and its gradient [2]:

The poly6 kernel, a smoothing function, was used to estimate the effect of nearby particles. The gradient of this kernel was used for calculating pressure gradient among other forces.

2. Compute density and pressure:

Density for each particle was ascertained by aggregating the contributions of neighboring particles, facilitated by the poly6 kernel. Following this, an equation of state was employed to ascertain the pressure corresponding to each particle's density.[3]

3. Compute forces from pressure gradient and gravity [4]:

The force due to pressure gradient was computed through the negative gradient of the pressure field. This force acts to balance any pressure discrepancies between neighboring particles. In addition to this, gravitational forces acting on individual particles were taken into consideration.

4. Compute acceleration and integrate:

The cumulative force on each particle was determined by summing up the forces due to pressure gradient and gravity. This cumulative force then facilitated the computation of each particle's acceleration, in line with Newton's second law. Lastly, integration of the acceleration was performed to update the velocity and position of each particle over time.

5. Handle boundary conditions:

It was critical to account for boundary conditions to avert the escape of water particles from the boundary and the penetration of the wall and house. I ensured that the particles remained confined within the pre-defined boundary of the world space. If a particle happened to cross the boundary, I made the necessary adjustments to its velocity and position to confine it within the boundary.

Through the implementation of these steps and proper management of boundary conditions, I could simulate fluid behavior using the SPH algorithm. This enabled the computation of density, pressure, forces, and acceleration, thus allowing for a realistic simulation of water particles as they interact with each other and the boundaries of the world space.

2 Investigation

2.1 Whether the house will be damaged or not

Running the simulation, with the initial condition given in the problem (the wall is 2m far from the house), water particles reach to the house, resulting in the house being **damaged**.

2.2 Minimum height of wall

The minimum height of the wall turns out to be when the **wall is 2.6m high**. When the wall is set to 2.5m, the particle goes over the wall reaching the house but when the wall is set to 2.6m, the particles do not reach the house.

2.3 Minimum distance between water and wall

Even though the wall is set the furthest away from the water and close to the house, **particles always reach the house** when the wall is 0.5m wide and 1m high. So the only way for the house to not be damaged is to increase the height of the wall.

2.4 Effect of increasing the accuracy of simulation

To increase the accuracy of simulation, we can think of it as decreasing the time step size since it influences the velocity and position of particles in each step. I've changed the time step values to 1, $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$, $\frac{1}{2000}$, $\frac{1}{3000}$, $\frac{1}{4000}$, $\frac{1}{5000}$ and there doesn't seem to be much difference as long as it is relatively small (smaller than approximately $\frac{1}{1000}$).

References

[1] J. P. Vila, "On particle weighted methods and smooth particle hydrodynamics." mathematical models and methods in applied sciences 9.02 (1999): 161-209.."

[2] J. J. Monaghan, "Smoothed particle hydrodynamics, annual review of astronomy and astrophysics 30.1 (1992): 543-574.."

[3] A. Colagrossi and M. Landrini, """numerical simulation of interfacial flows by smoothed particle hydrodynamics." journal of computational physics 191.2 (2003): 448-475.."

[4] J. P. Morris, "Analysis of smoothed particle hydrodynamics with applications. australia: Monash university, 1996.."